A Pragmatic Global Vision System for Educational Robotics (and its use in a Mixed-Reality Approach to Robot Education)

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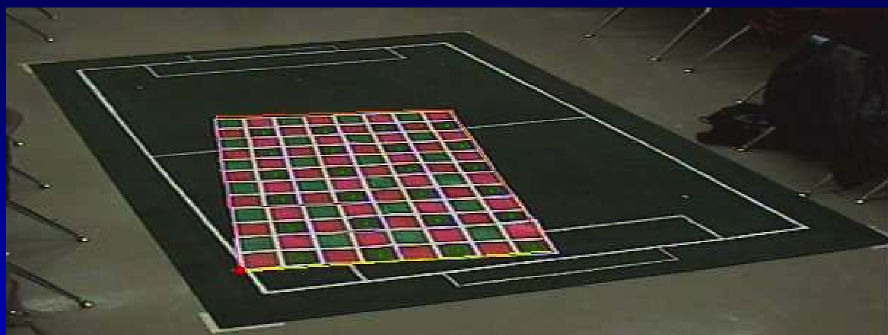
Vision

- Richest sense, also the most difficult to handle well in an educational setting
- Computational demands, demands on sophistication of students
- Local vs. Global vision is our main separator between undergraduate and graduate robotics
- *Global vision can be a useful tool to allow undergraduates to work in sophisticated domains and gain some understanding of the complexities of vision, without overwhelming them*
    - RoboCup ULeague [Sklar et al.], PV (Eco-B) League

Necessary Features

- Fast Tracking – practical use in fast domains
- Ease of setup: Limited restrictions, ease of calibration, limited need for recalibration
- Function well under a wide range of lighting conditions
- Students should ultimately be able to set up/calibrate the vision server itself, and learn about some of the issues in providing vision to a team of robots without being overwhelmed
- Doraemon: No requirement for an overhead camera, fast setup

Doraemon



- Tsai camera calibration
- Acts like a server, taking frames and producing a description of objects (coordinates, velocity, strength of match) over Ethernet
- Objects are an arrangement of colored patches of a given size
- Sophisticated 12 parameter color model including difference channels, but still dependent on calibrating colors, recalibration due to lighting shifts

Ergo

- Work to improve Doraemon in order to make it more robust and ultimately more useful by students
- Eliminate need for continual recalibration as lighting shifts, need to define colors, need to separate these in the spectrum for good performance
- Accurate vision over as wide a range of conditions, with as few underlying assumptions as possible.
- Focus on intelligent, adaptive approaches that do not require specialized hardware

Overview of standard GV systems:

- Classify all pixels in the image according to calibrated color values.
- Join like colors into regions.
- Search the regions for patterns that describe robots or the ball.
- Map image coordinates of found objects back to real-world coordinates.

Overview of our tracking system:

- Reconstruct overhead view of field from camera placed at oblique angle
- Remove the static background from the reconstructed image
- Collect foreground pixels into regions
- Search regions for a robot that may be identified by a novel pattern that does not require predefined color

Overhead view reconstruction:

- Map pixels in captured images using the well-established Tsai camera calibration.
- The expense of this operation and the real-time constraint must be balanced.
- This results in a low resolution reconstructed image (640x240 -> 125x76).

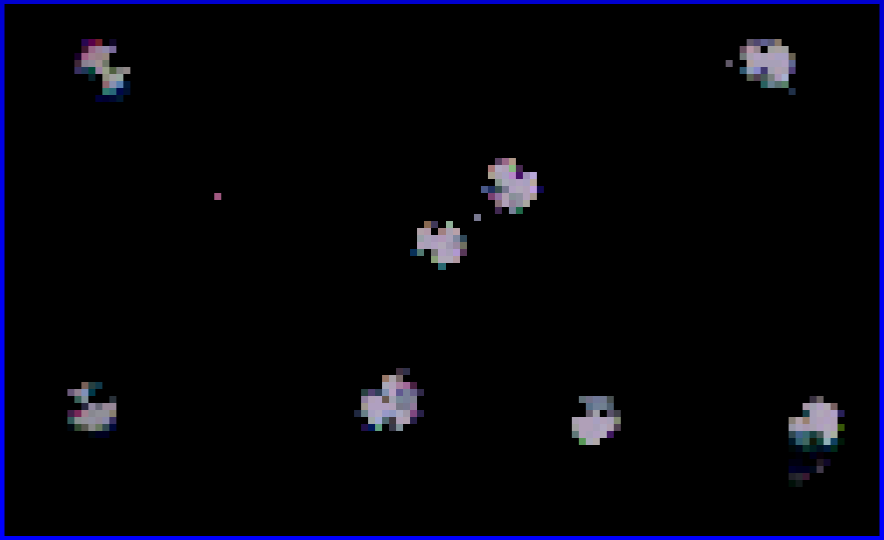
Background removal:

- Problem: Noise from inexpensive cameras, downsampling confounds accurate background differencing. Especially significant for small objects
- Solution:
  - Estimate the variance of each pixel while collecting the background; compute a threshold for each pixel based on the variance of itself and neighboring pixels
  - For each incoming image, compute the sum-squared-error of each incoming pixel from the background pixel
  - Use the sum-squared-error of the pixel together with its neighbors to determine if there is motion in the pixel
- Works well against single-pixel noise while drawing out small objects

Background removal:

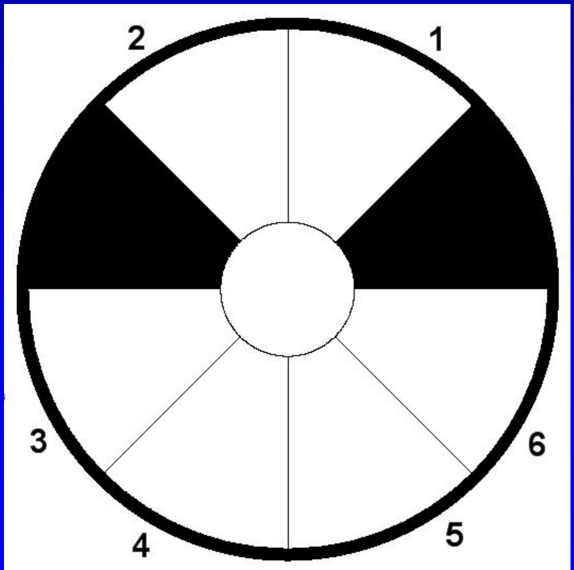
Reconstructed frame:

Background removed:



Robot Identification:

- Novel pattern design allows 62 individual robots to be distinguished without the use of predefined color



- black wedges define robot orientation.
- White and “other” (neither white nor black) wedges in the remaining spaces define a bit pattern that distinguishes individual robots.

Robot Identification:

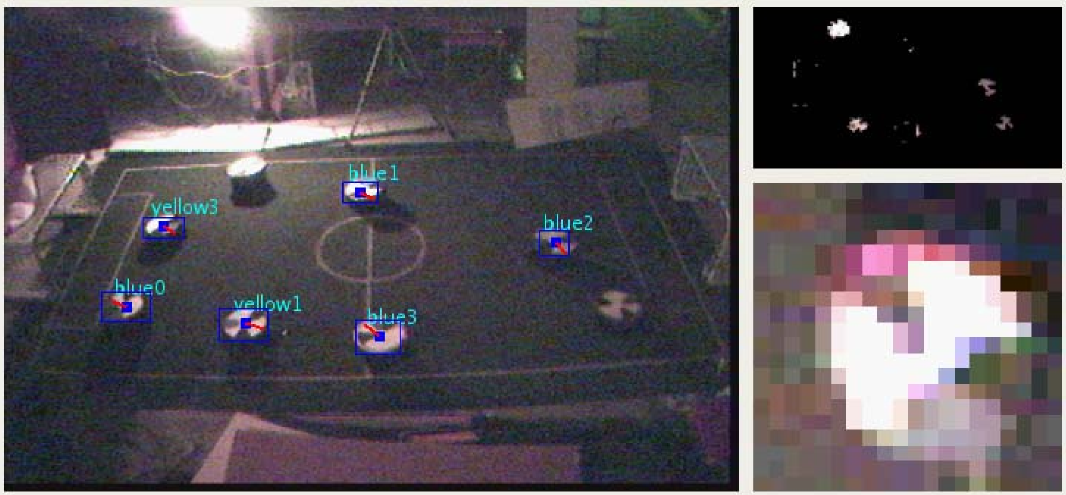
- Estimate the center of tracking pattern as the center of the a region.
- Interpolate a high-resolution strip around the center.
- Median filter and apply edge-detection to determine the white-to-black and black-to-white transitions.
- Finding two black wedges confirms that we have found a robot and gives the robot's orientation.

Robot Identification:

- An examination of the histogram of intensities along the strip gives allows the white, and “other” color regions to be differentiated
- The use of local intensity difference and edge detection along the strip allows the robot identification process to be totally indifferent to the color used

Uneven Lighting:

- Because the robot identification uses local differences, the system may be used under uneven lighting conditions:



	Name	Type	x	y	dx	dy	theta	Found
1	blue0	Robot::6	310.73	394.00	-0.04	-0.03	2.72	100%
2	blue1	Robot::4	1280.95	1172.71	0.01	0.00	-0.76	100%
3	blue2	Robot::3	2149.56	729.63	-0.00	-0.00	-1.26	95%
4	blue3	Robot::1	1373.85	210.70	-0.00	-0.00	2.25	100%
5	yellow0	Robot::8	2330.39	320.82	0.02	0.02	-2.32	
6	yellow1	Robot::1	843.32	293.47	-0.00	0.00	-0.33	94%
7	yellow2	Robot::1	2320.83	309.00	0.01	-0.00	-2.29	
8	yellow3	Robot::3	342.03	933.63	0.00	0.00	-0.69	100%

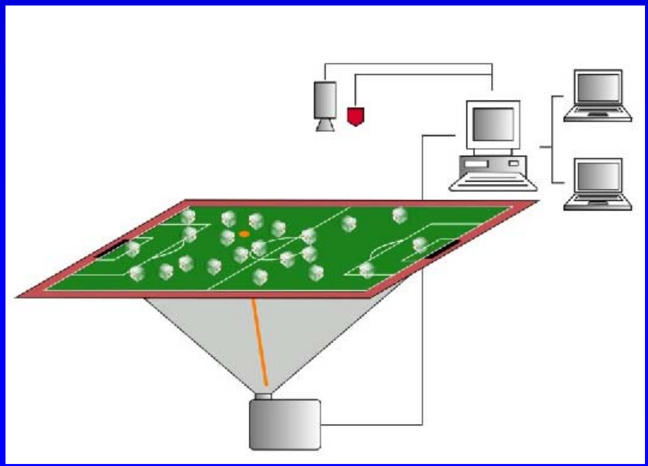
- Maintains a frame rate of 28-35 fps while tracking eight robots.

Ergo in an Educational Setting

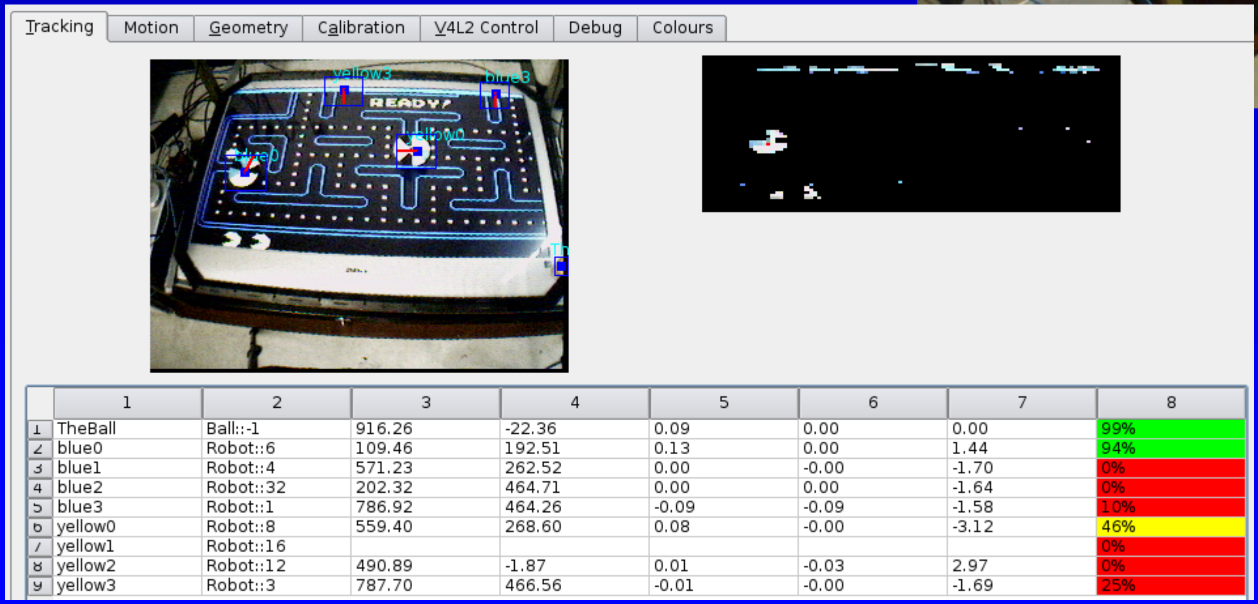
- Students begin using global vision on the first day of a (fourth-year) class. Class covers perspective geometry of a standard pinhole camera without implementation
- Laboratory session to learn to use Ergo. Understand enough about vision to calibrate the system and understand practicalities (occlusion, tracking errors)
- Set up for them to begin with, and they naturally take over using it themselves

Small Scale/Mixed Reality

- 2” infrared tanks, moving to Citizen Eco-B robots for the RoboCup PV league



Ergo in use with Mixed Reality



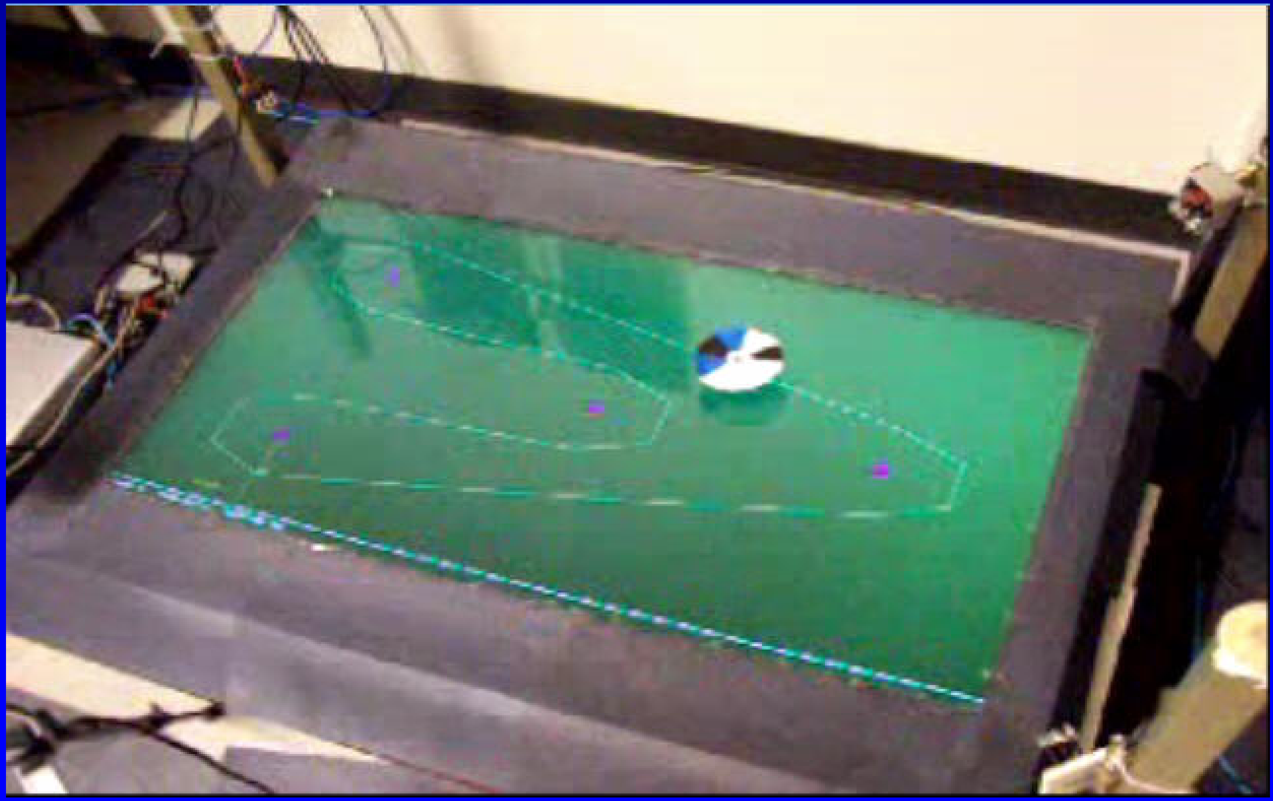
	1	2	3	4	5	6	7	8
1	TheBall	Ball::-1	916.26	-22.36	0.09	0.00	0.00	99%
2	blue0	Robot::6	109.46	192.51	0.13	0.00	1.44	94%
3	blue1	Robot::4	571.23	262.52	0.00	-0.00	-1.70	0%
4	blue2	Robot::32	202.32	464.71	0.00	0.00	-1.64	0%
5	blue3	Robot::1	786.92	464.26	-0.09	-0.09	-1.58	10%
6	yellow0	Robot::8	559.40	268.60	0.08	-0.00	-3.12	46%
7	yellow1	Robot::16						0%
8	yellow2	Robot::12	490.89	-1.87	0.01	-0.03	2.97	0%
9	yellow3	Robot::3	787.70	466.56	-0.01	-0.00	-1.69	25%

Mixed Reality

- One way of *KEEPING IT INTERESTING*,
  - Robots are always interesting, but having a fun element helps push students through frustrating moments
- but also allows non-robot objects to be generated and controlled during trials, and easy re-configuration
- Begin by controlling robots remotely on field (e.g. DDR) using visual feedback from the vision server, while learning basic control models in class (Balluchi, Egerstedt, fuzzy logic)

Assignment Stage 2

- Use visual feedback from the server to follow paths ("auckindy") to apply path following while learning path planning (e.g. quad-tree, Voronoi diagrams)

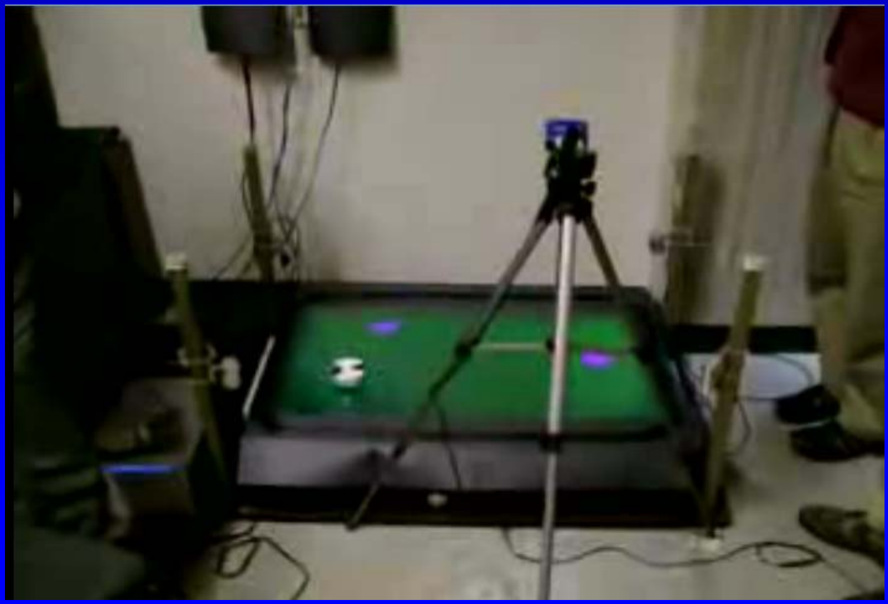


Assignment Stage 3

- Plan paths to perform a treasure hunt while learning dynamic obstacle avoidance in class

Assignment Stage 4

- Build dynamic obstacle avoidance systems (obstacle avoidance, pong) while learning more sophisticated behaviour-based control mechanisms (e.g. behaviour trees)
  - Perception still from vision server, not simulated world model



Capstone

- Demonstrate skills requiring sophisticated behaviours (e.g. passing control), and put these together into a full application

Capstone

- Example Applications: 2-on-2 soccer, Pac-Man

Moving Beyond a Course

- Ultimately, students are motivated enough to work beyond class toward a team that could be put into competition (ULeague, PVLeague, FIRA)
- Ergo is available from our website: http://www.cs.umanitoba.ca/~aalab
  - QT-based, easier install/build than Doraemon

Summary

- Ergo allows students to get started with vision quickly, and ultimately support the system itself
- Approach requires very infrequent recalibration (color still needed for the ball when motion fails to detect it)
- Allows students to work with interesting projects without getting overloaded with the sophistication involved in vision
- Mixed reality is an interesting addition to the tools we have to motivate robotics to students